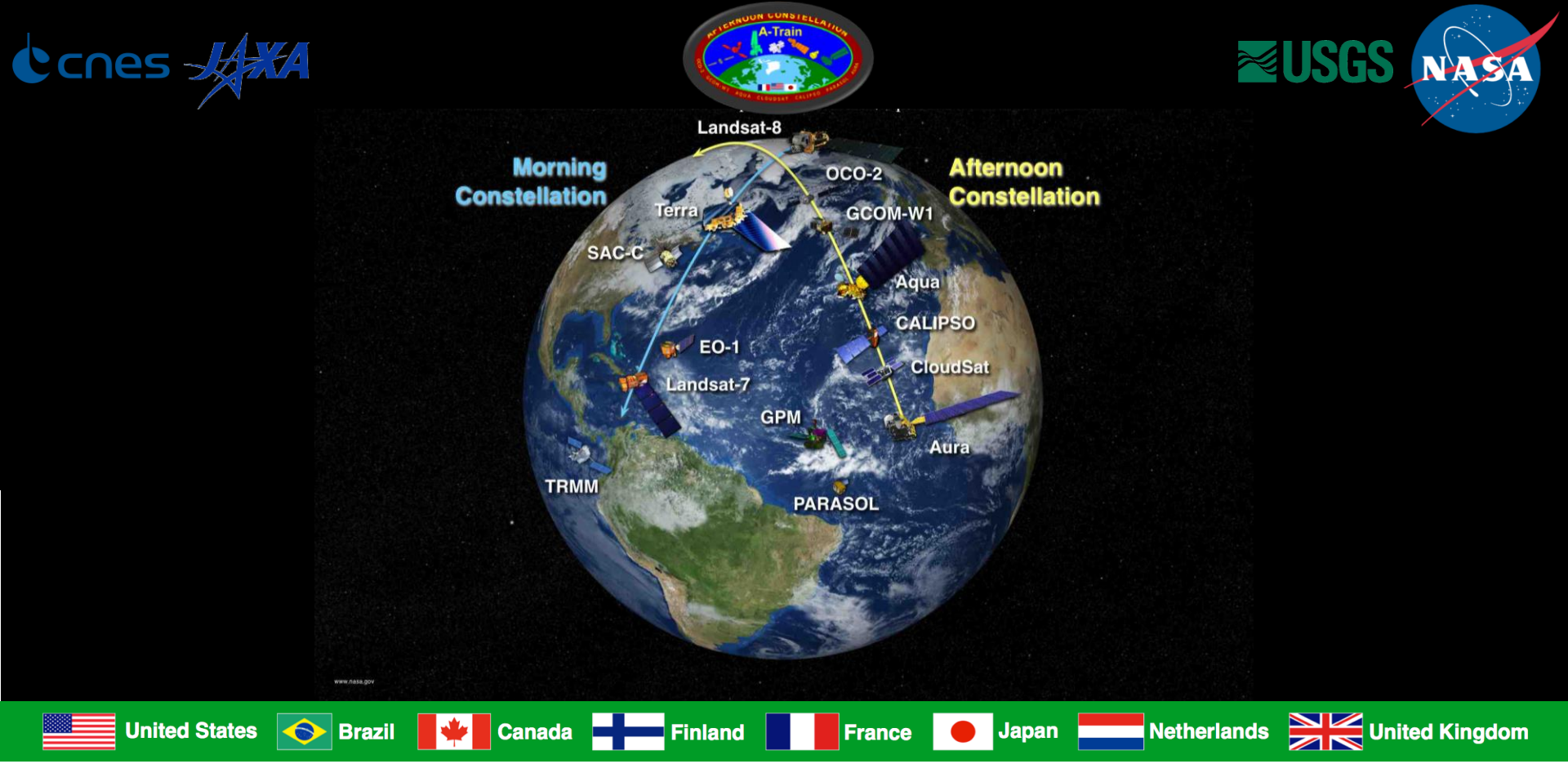

International Earth Science Constellation Mission Operations Working Group

April 13-15, 2016

Aqua Spring 2016 IAM Campaign and No-Slew DMU Results

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Agenda

- Aqua 2016 IAM Campaign - results so far
- 2017 IAM Campaign Dates
- Aqua Long Term Maneuver Predictions
- Aqua/Aura No-Slew DMU Maneuver Results

Aqua Spring 2016 Series Summary

- Aqua will perform **4** inclination maneuvers from March **18th** to April **22nd**
- After three Aqua Inc maneuvers, the total inclination change is **1.21% cold** compared to the latest 2016 IAM predictions delivered to MOWG members

Inc #	Date	Burn Duration (sec)	Predicted Delta - Inc (deg)	Achieved Delta-Inc (deg)	Predicted Delta - RAAN (deg)	Achieved Delta - RAAN (deg)	Predicted Delta - V (m/s)	Achieved Delta - V (m/s)
48	09-Mar-2016	550	-0.0084	-0.0087	0.00150	0.00110	1.134	1.132
49	16-Mar-2016	550	-0.0085	-0.0082	0.00105	0.00050	1.127	1.130
50	06-Apr-2016	550	-0.0085	-	-0.00031	-	1.121	-
51	20-Apr-2016	550	-0.0084	-	-0.00112	-	1.117	-
		Totals:	-0.0338	-0.0431	0.00112	-0.00024	4.499	5.710

delta-I difference:	0.00053	deg
percent error:	-1.21%	COLD

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Aqua/Aura 2016 Maneuver Schedule

Aqua/Aura 2016 Inclination Maneuver Series Schedule

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		March 1	2	3	4	5
6	7	8	9 Aqua IAM#48	10 Aura IAM#45	11	12
13	14	15	16 Aqua IAM#49	17 Aura IAM#46	18	19
20	21	22	23	24	25	29
27	28	29	30	31	April 1	2
3	4	5	6 Aqua IAM#50	7 Aura IAM#47	8	9
10	11	12	13	14	15	16
17	18	19	20 Aqua IAM#51	21 Aura IAM#48	22	23
24	25	26	27	28	29	30
May 1	2	3	4 Aqua Backup	5 Aura Backup	6	7

Aqua/Aura Spring 2017 Campaign

- Aqua has **4** inclination maneuvers planned for Spring 2017
  - Aqua's predicted ideal burn date occurs on **Mar 09, 2017**
  - **4** maneuvers will occur on or after the ideal burn date
- Aura has **4** inclination maneuvers planned for Spring 2017
  - Aura's predicted ideal burn date occurs on **Mar 26, 2017**
  - **4** maneuvers will occur after the ideal burn date

Note: performing maneuvers off of the ideal date slightly decreases burn efficiency

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Aqua/Aura 2017 Maneuver Schedule

Aqua/Aura 2016 Inclination Maneuver Series Schedule

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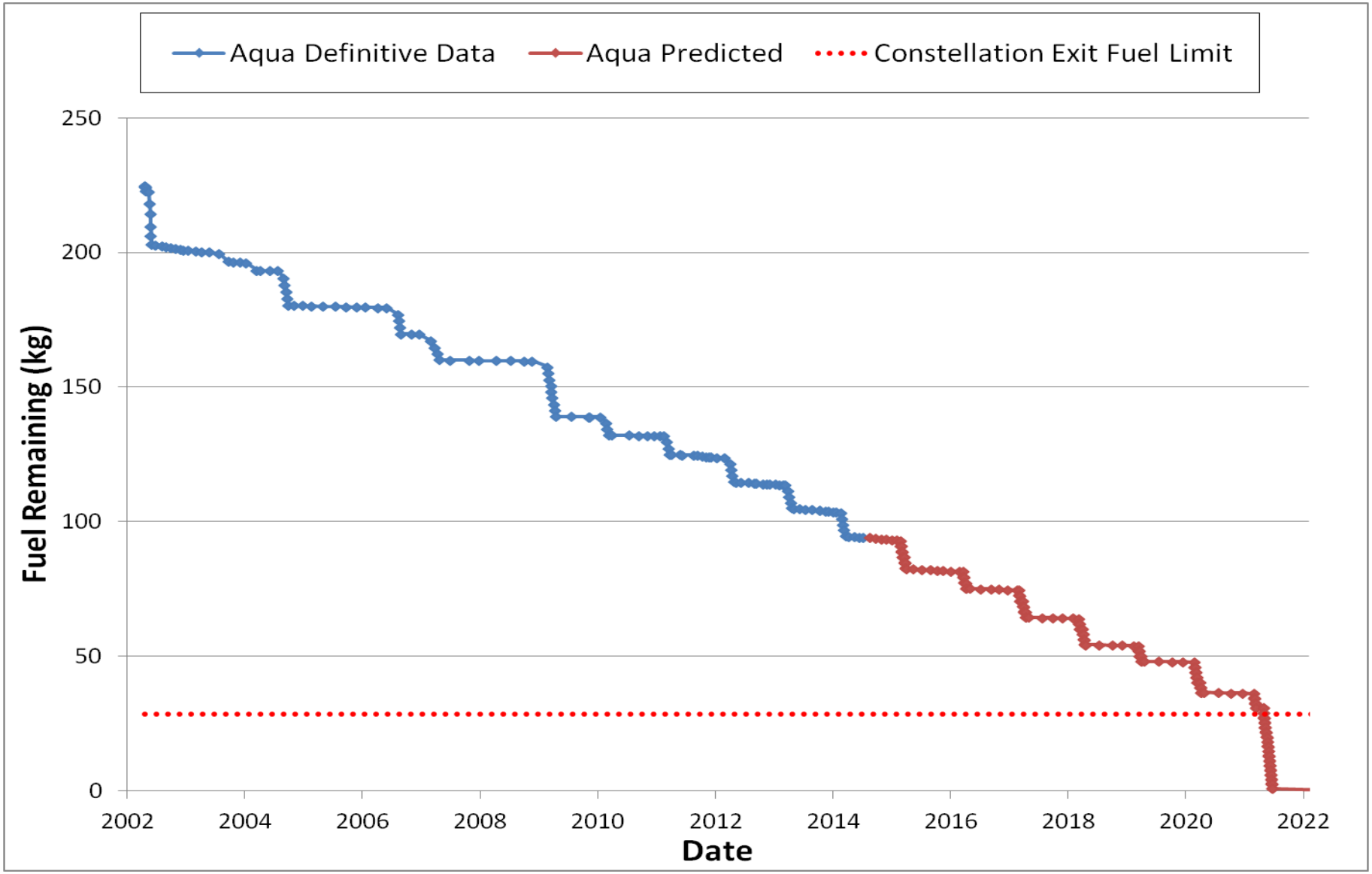
		March 1	2	3	4	5
6	7	8	9 Aqua IAM#48	10 Aura IAM#45	11	12
13	14	15	16 Aqua IAM#49	17 Aura IAM#46	18	19
20	21	22	23	24	25	29
27	28	29	30	31	April 1	2
3	4	5	6 Aqua IAM#50	7 Aura IAM#47	8	9
10	11	12	13	14	15	16
17	18	19	20 Aqua IAM#51	21 Aura IAM#48	22	23
24	25	26	27	28	29	30
May 1	2	3	4 Aqua Backup	5 Aura Backup	6	7

Aqua Long-Term Predictions

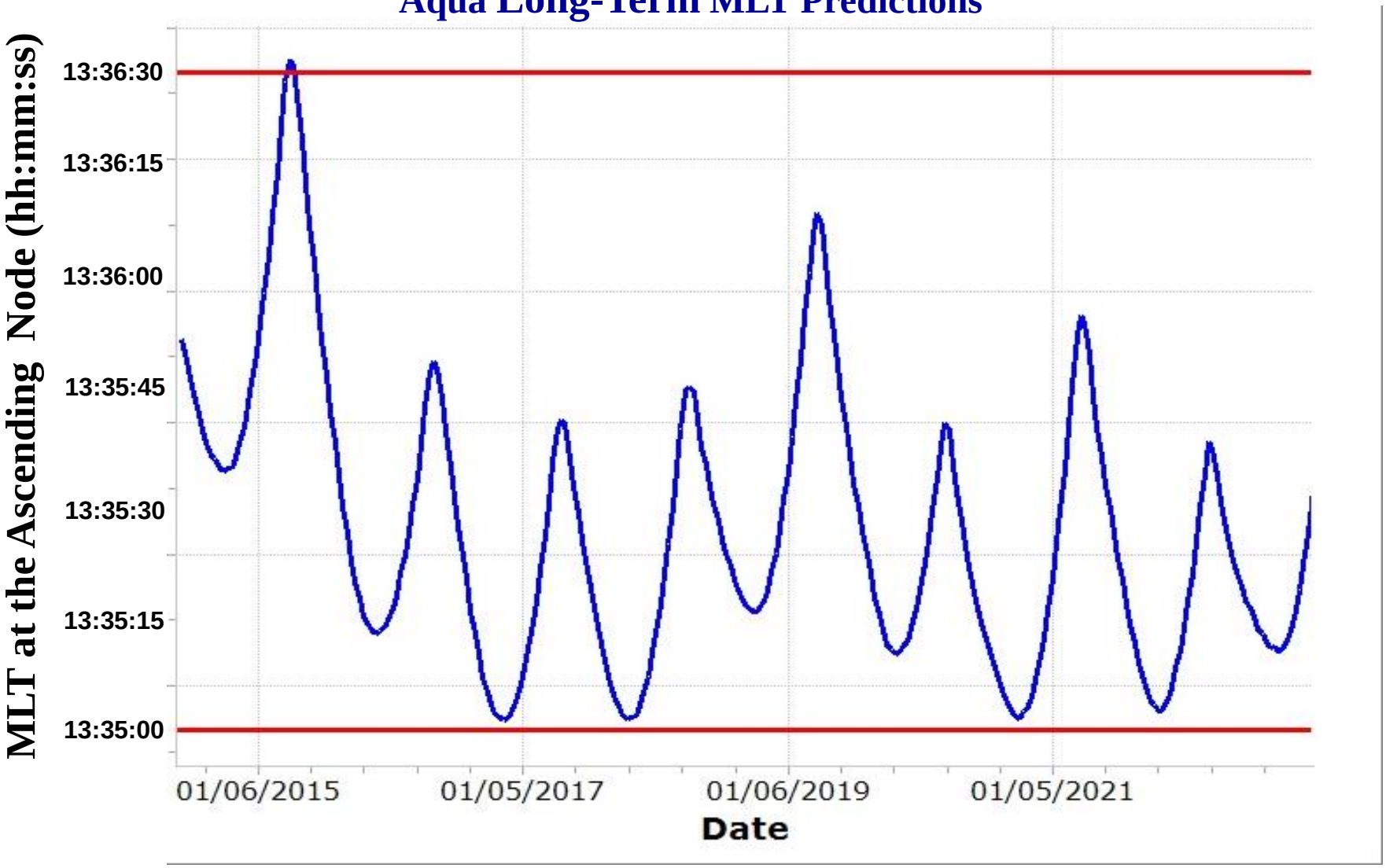
- From the 2015 Aqua Lifetime Report, Aqua has enough fuel to complete full inclination series through **2020**, assuming 10kg unusable fuel and **28.4** kg fuel remaining for constellation exit and orbit lowering burns to meet the 25 year reentry requirement.

Inclination Series	Number of Maneuvers	Burn Duration (sec)	Total Δi (deg)	Total Δv (m/s)
Spring 2017	4			
Spring 2018	4			
Spring 2019	5			
Spring 2020	4			

Aqua Fuel Usage and Projections



Aqua Long-Term MLT Predictions



Aqua's MLT requirement is 13:30 ±15 minutes. The mission has agreed to fly within tighter bounds for improved science data collection and more repeatability of delta-I maneuvers from year to year.

Aqua/Aura No-Slew DMU Maneuver Results

No-Slew DMU Background

- Performing drag makeup maneuvers (DMU) and risk mitigation maneuvers (RMM) without slewing the spacecraft is operationally desirable
- Under no-slew operations, a small out-of-plane delta-v component is introduced during DMU/RMM maneuvers
- Previous analysis has shown that performing no-slew maneuvers at the poles minimizes the change in inclination due to the out-of-plane thrust
  - Change in RAAN can be nominally canceled out by executing maneuvers in pairs at opposing poles (“mirror pole maneuvers”)
  - Introduces small negative effect on frozen orbit (eccentricity vs. argument of perigee)
- Using the mirror pole strategy reduces the overall impact to the MLT

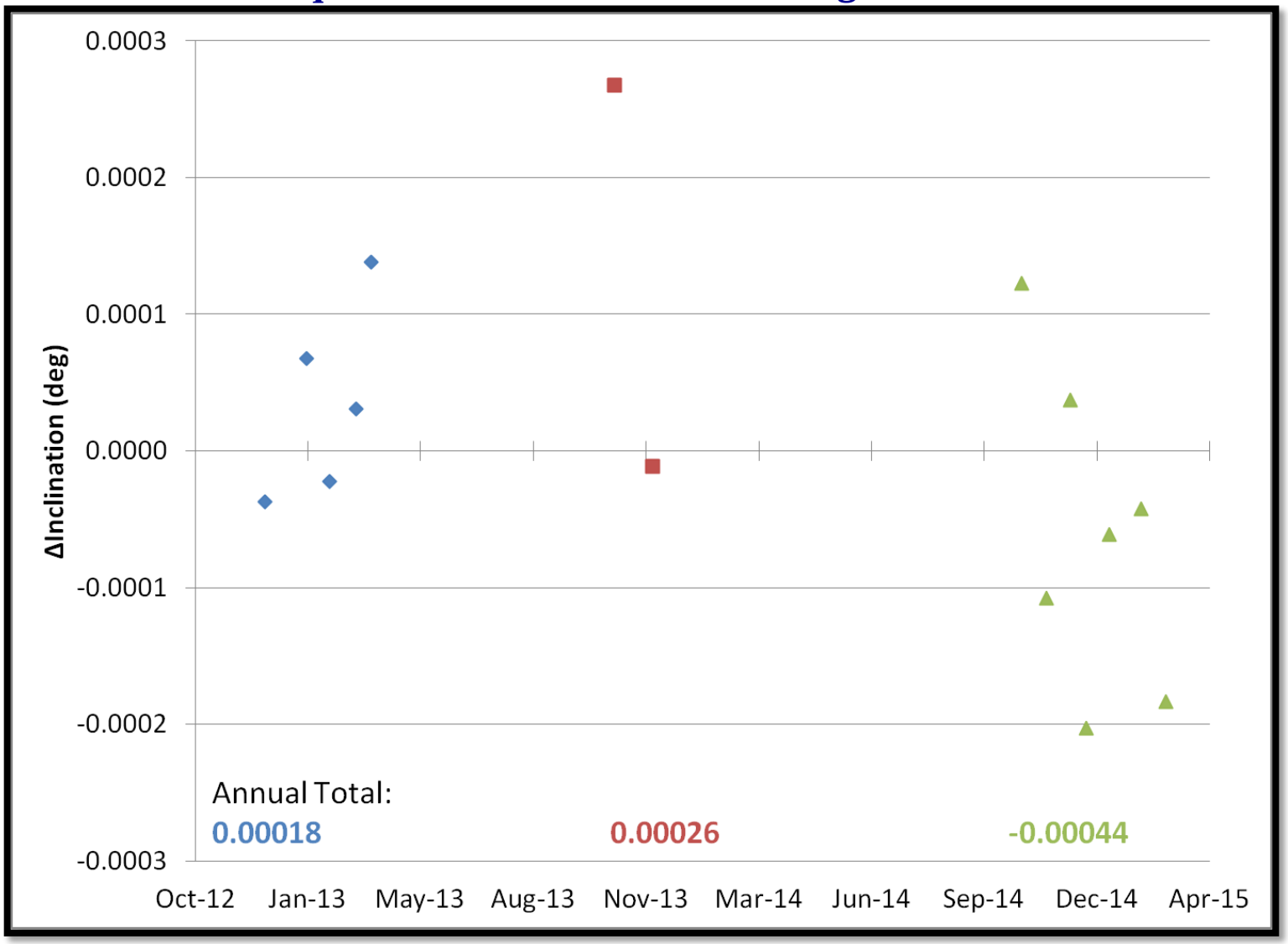
No-Slew DMU Background

- Aura has been performing no-slew maneuvers exclusively since December 2012
- Between 2012 and October 2014 Aqua performed slewed DMU maneuvers and no-slew RMM maneuvers
- Since October 2014 Aqua has performed no-slew maneuvers exclusively for both DMU and RMM
- Aqua and Aura now operate with a hybrid maneuver scheme
  - DMU maneuvers are nominally performed at alternating pole locations
  - RMM locations are dictated by conjunction timing and geometry
  - 1 to 2 frozen orbit maneuvers are added per year to maintain frozen orbit requirements

Aqua No-Slew Demonstration Results

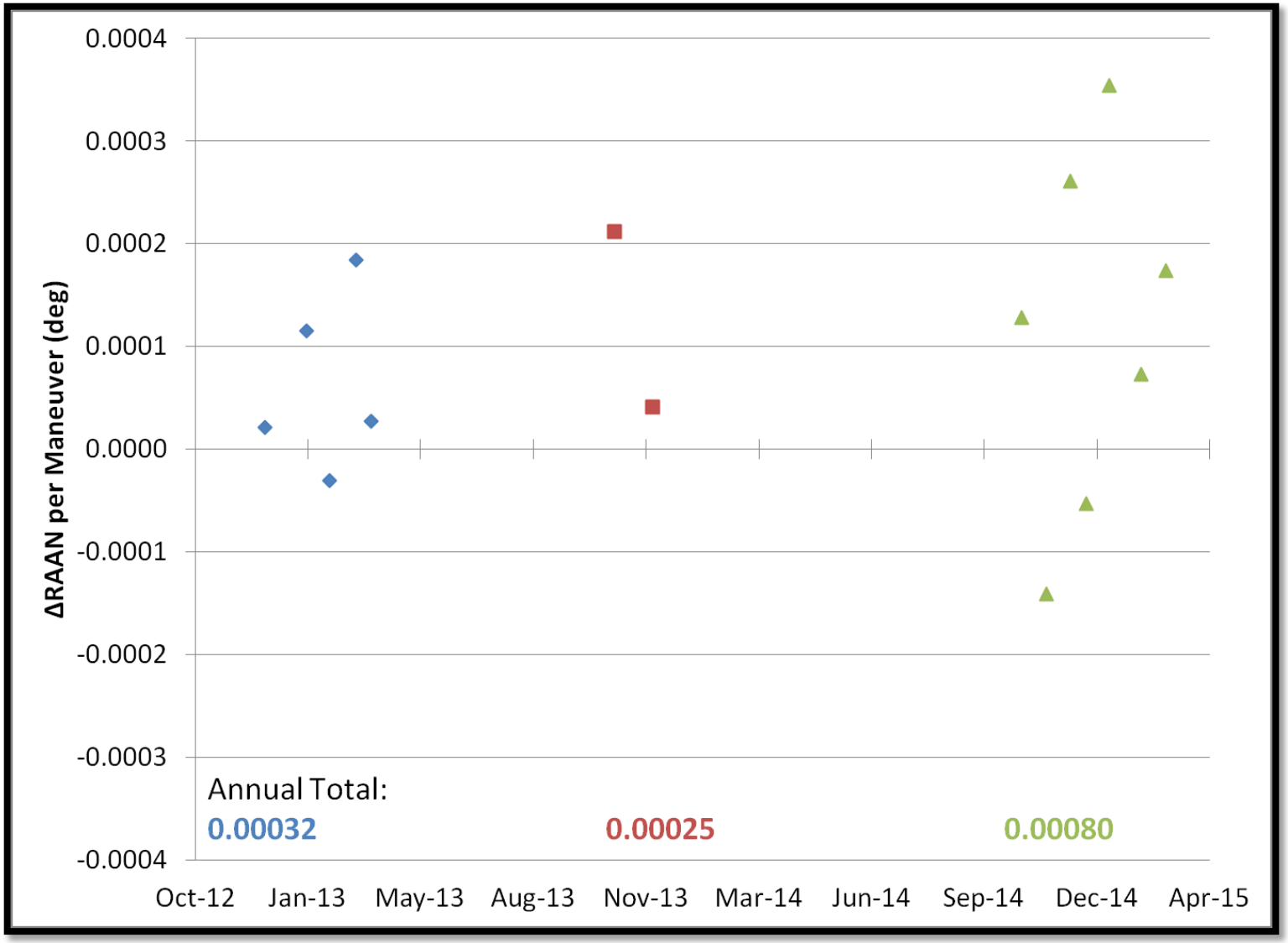
- Aqua has executed 14 no-slew maneuvers since December 19, 2012
- The observed SMA error for no-slew maneuvers is ±6.9% difference in the predicted vs. definitive data
  - Excludes the first no-slew maneuver
  - Includes both DMU and RMM maneuvers
  - Historical slewed maneuvers had an accuracy of ±6.5%
  - Prediction accuracy will increase as more data is collected for various burn durations and orbit locations
  - No-slew maneuvers have been sized from 3.0 – 60.0 seconds

Aqua No-Slew Inclination Change Results



Annual Δinclination induced by no-slew maneuvers has been minimal

Aqua No-Slew RAAN Change Results

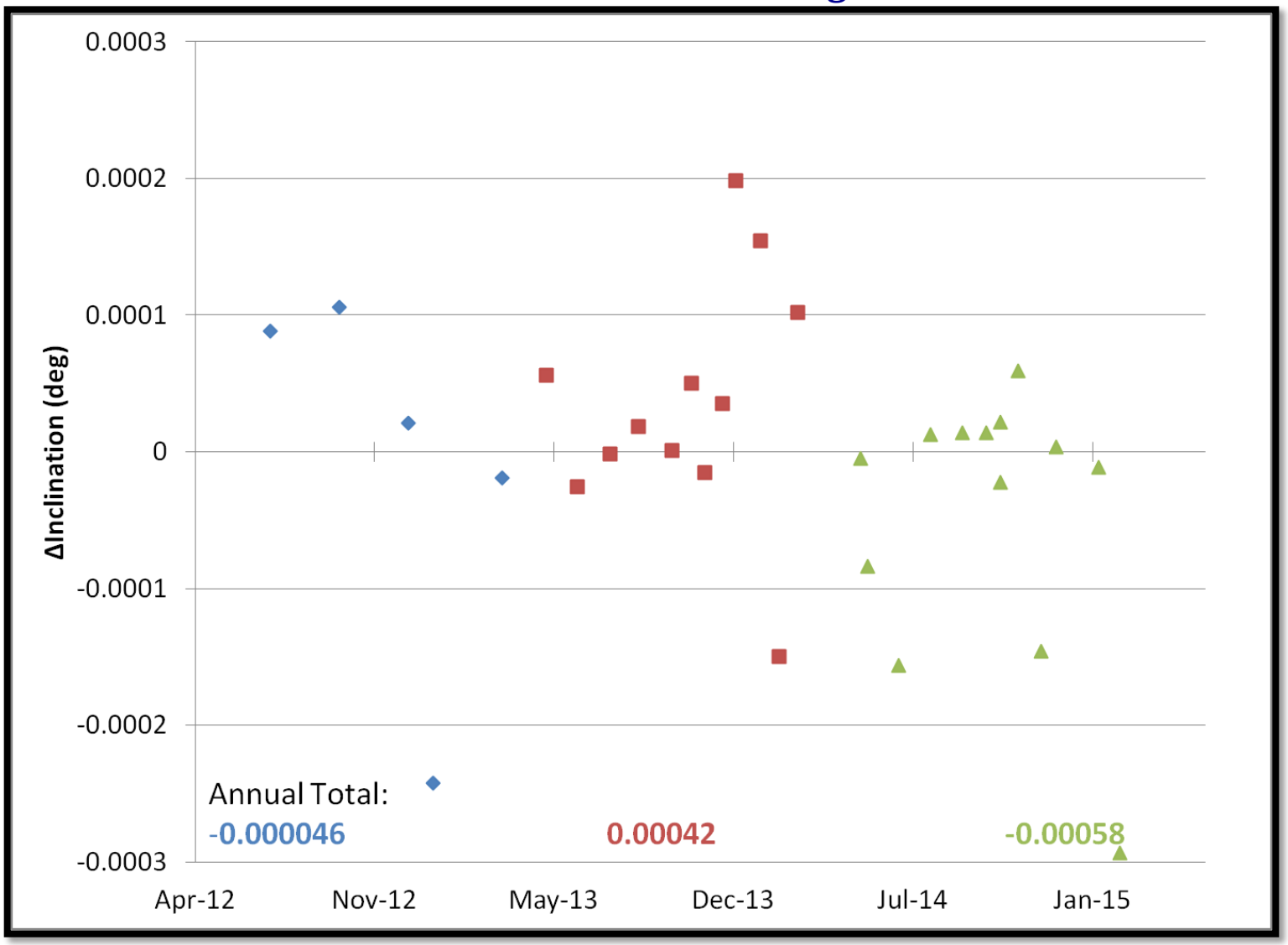


Annual ΔRAAN induced by no-slew maneuvers has been minimal

Aura No-Slew Demonstration Results

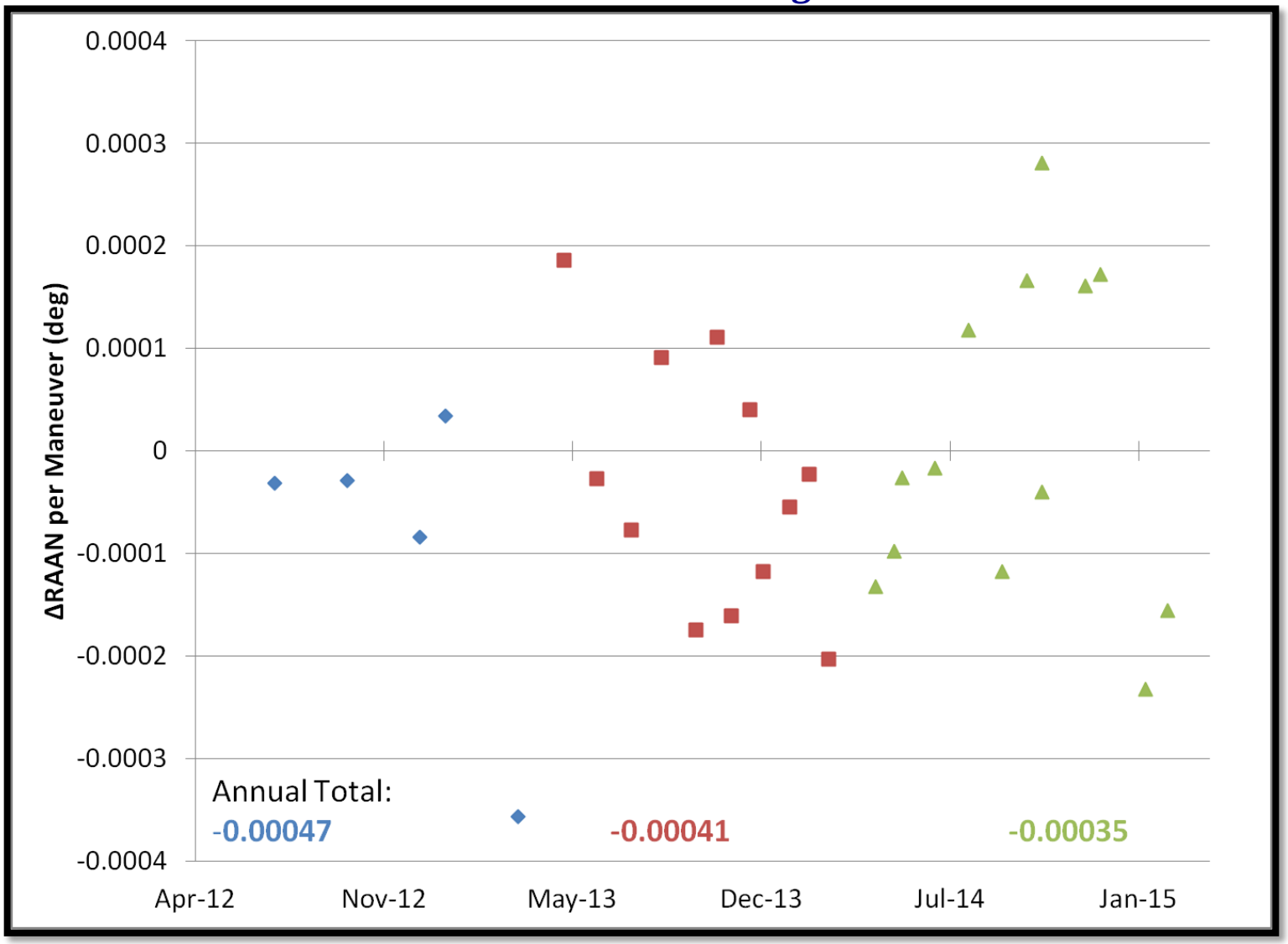
- Aura has executed 32 no-slew DMU maneuvers since July 19, 2012
- The observed SMA error for no-slew maneuvers is ±2.1% difference in the predicted vs. definitive data
  - Excludes the first no-slew maneuver
  - Historical slewed maneuvers had an accuracy of ±3.1%
  - Current prediction accuracy is now comparable to historical slewed accuracies
  - No-slew maneuvers have been sized from 8.0 – 44.0 seconds

Aura No-Slew Inclination Change Results



Annual Δinclination induced by no-slew maneuvers has been minimal

Aura No-Slew RAAN Change Results



Annual ΔRAAN induced by no-slew maneuvers has been minimal

Backup

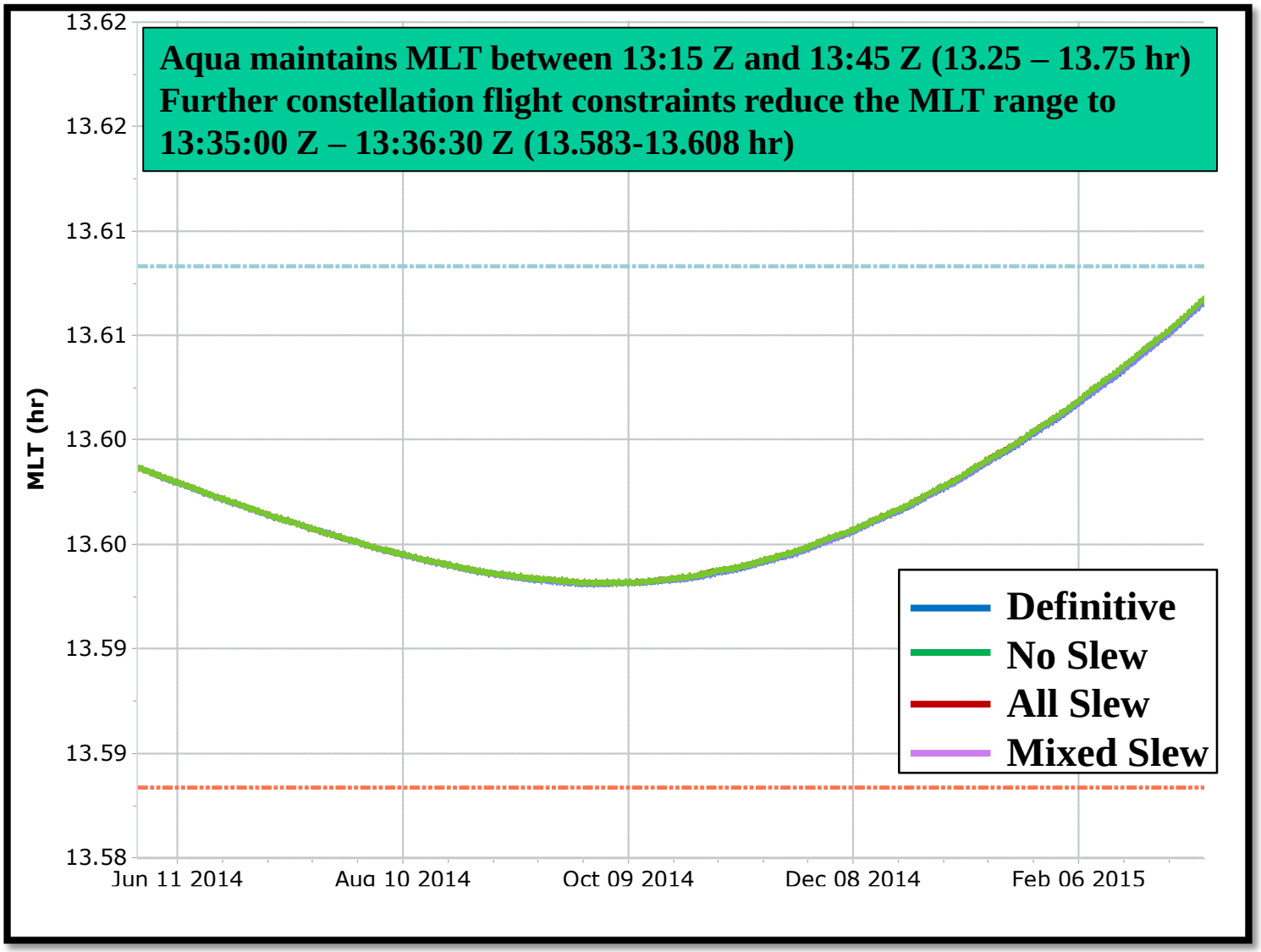
- No-Slew DMU Predicted vs. Definitive comparisons
  - Number of maneuvers
  - Inclination difference
  - RAAN difference
  - Frozen orbit evolution

Aqua Maneuver Predictions

- Between the Spring 2015 and the Spring 2016 IAM campaigns Aqua performed substantially more DMUs than predicted in all three lifetime analysis performed in summer 2015
- Operationally, the spacecraft maneuvers more frequently due to desired WRS "buffer" not accounted for in Lifetime predictions

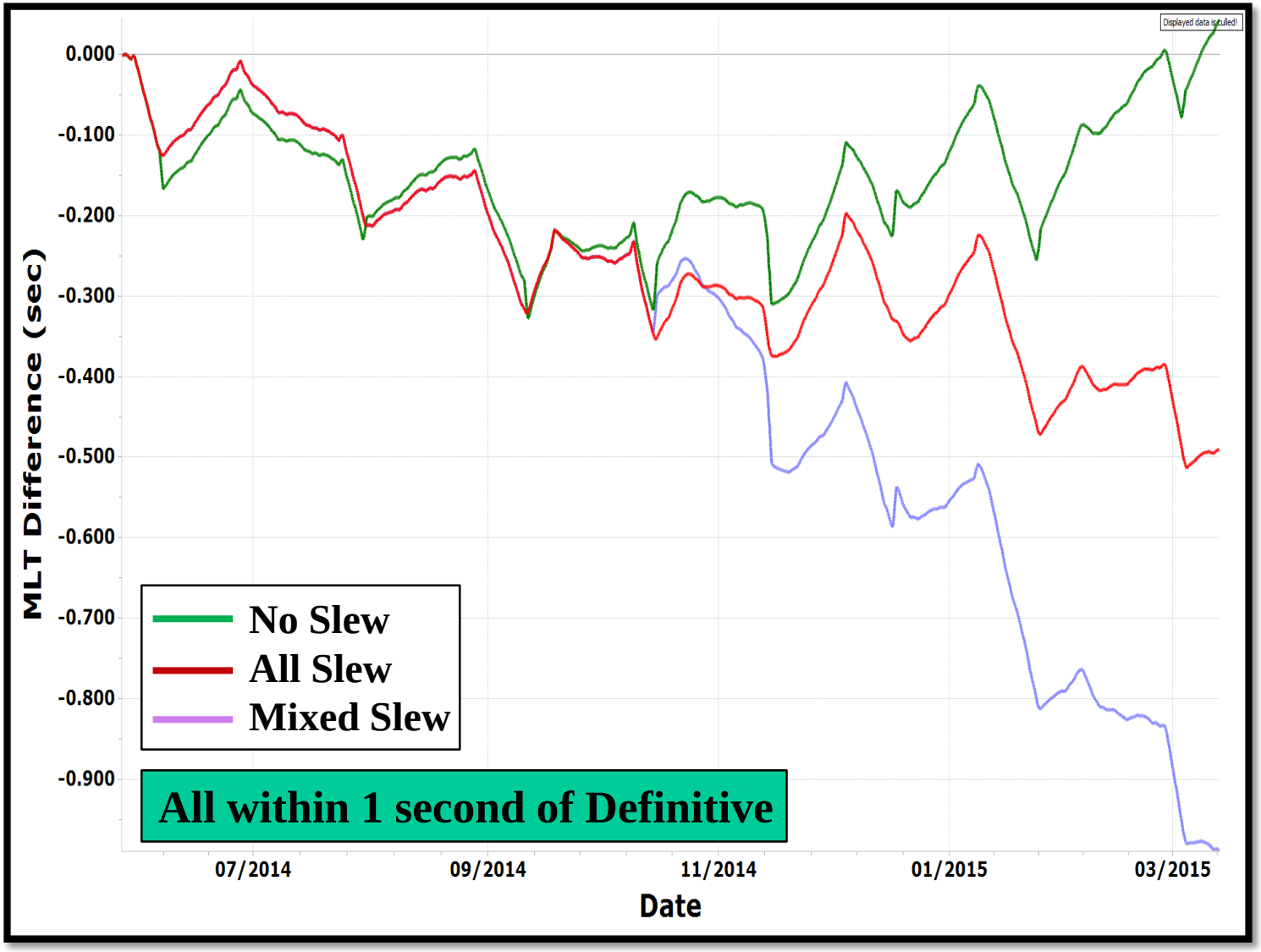
Maneuver Type	Definitive Maneuver Count	Summer Lifetime Count
DMU – Slewed Frozen Orbit	8	6
DMU – No-Slew Mirror Pole	6	4
DMU – No-Slew Frozen Orbit	1	0
Total	15	10

Aqua MLT - Zoomed

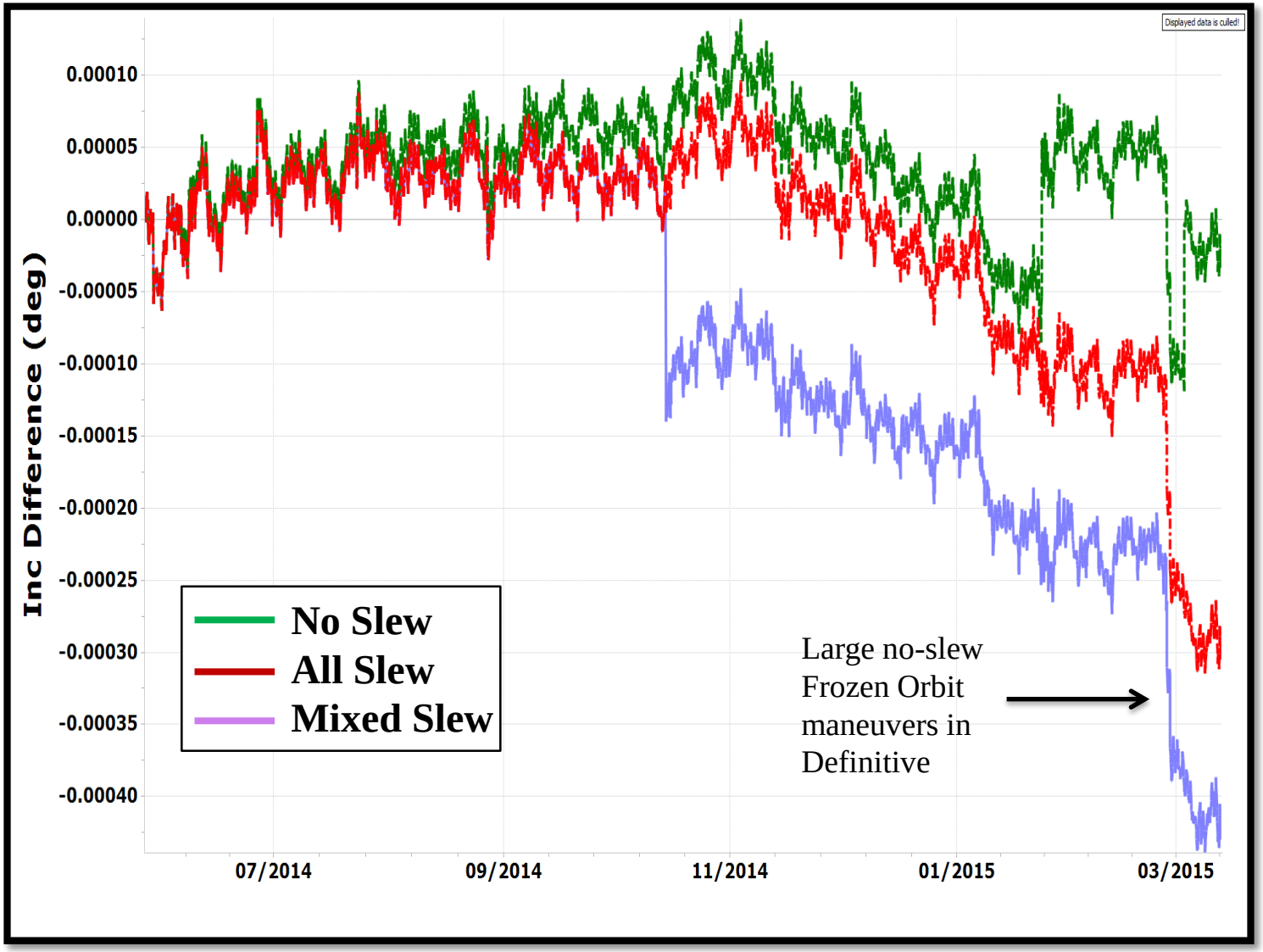


Note: Lines overlay

Aqua MLT Difference: Definitive - Predicted

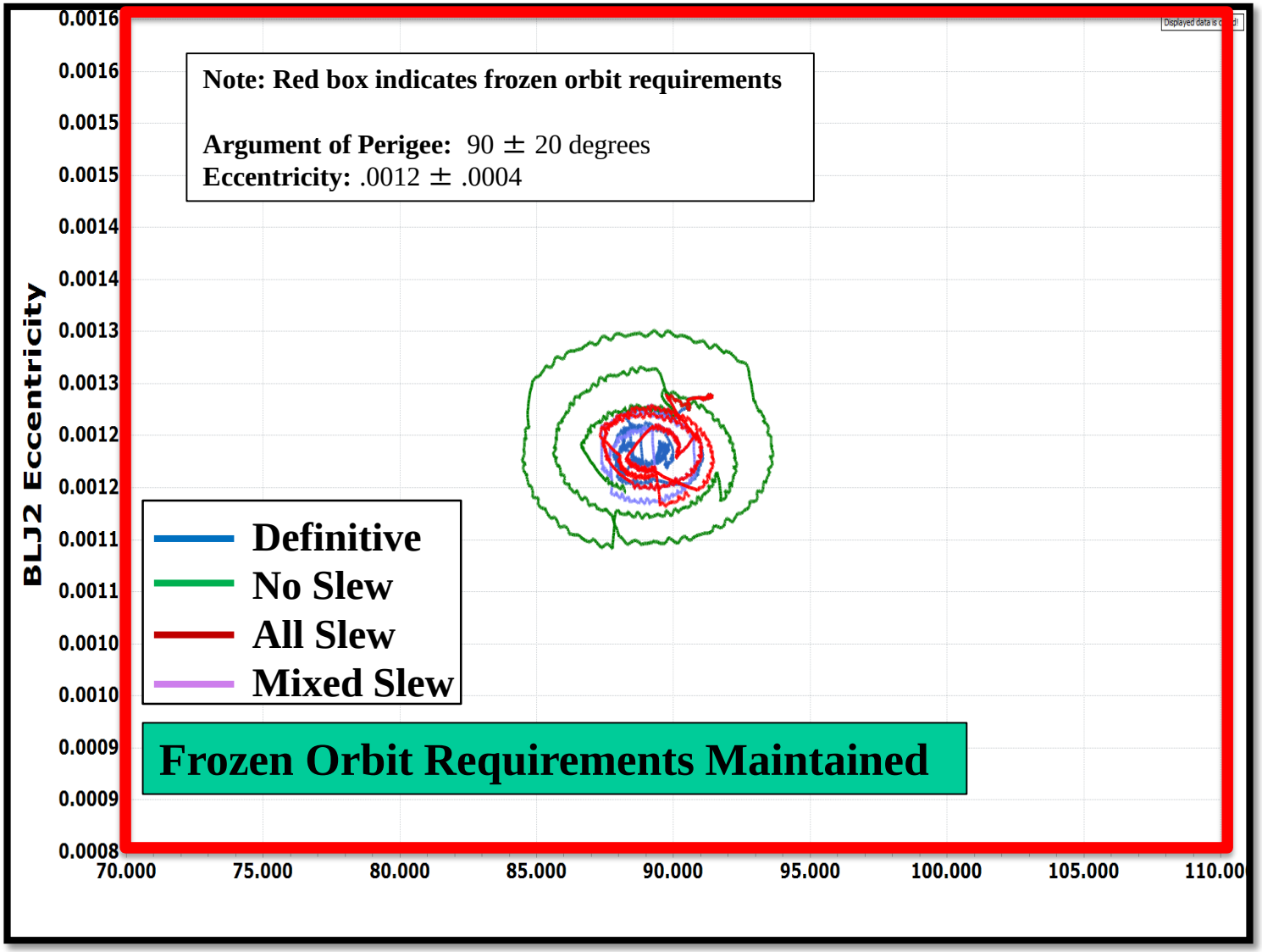


Aqua Inclination Difference: Definitive - Predicted



Aqua RAAN Difference: Definitive - Predicted

Aqua Comparison of Frozen Orbit Parameters



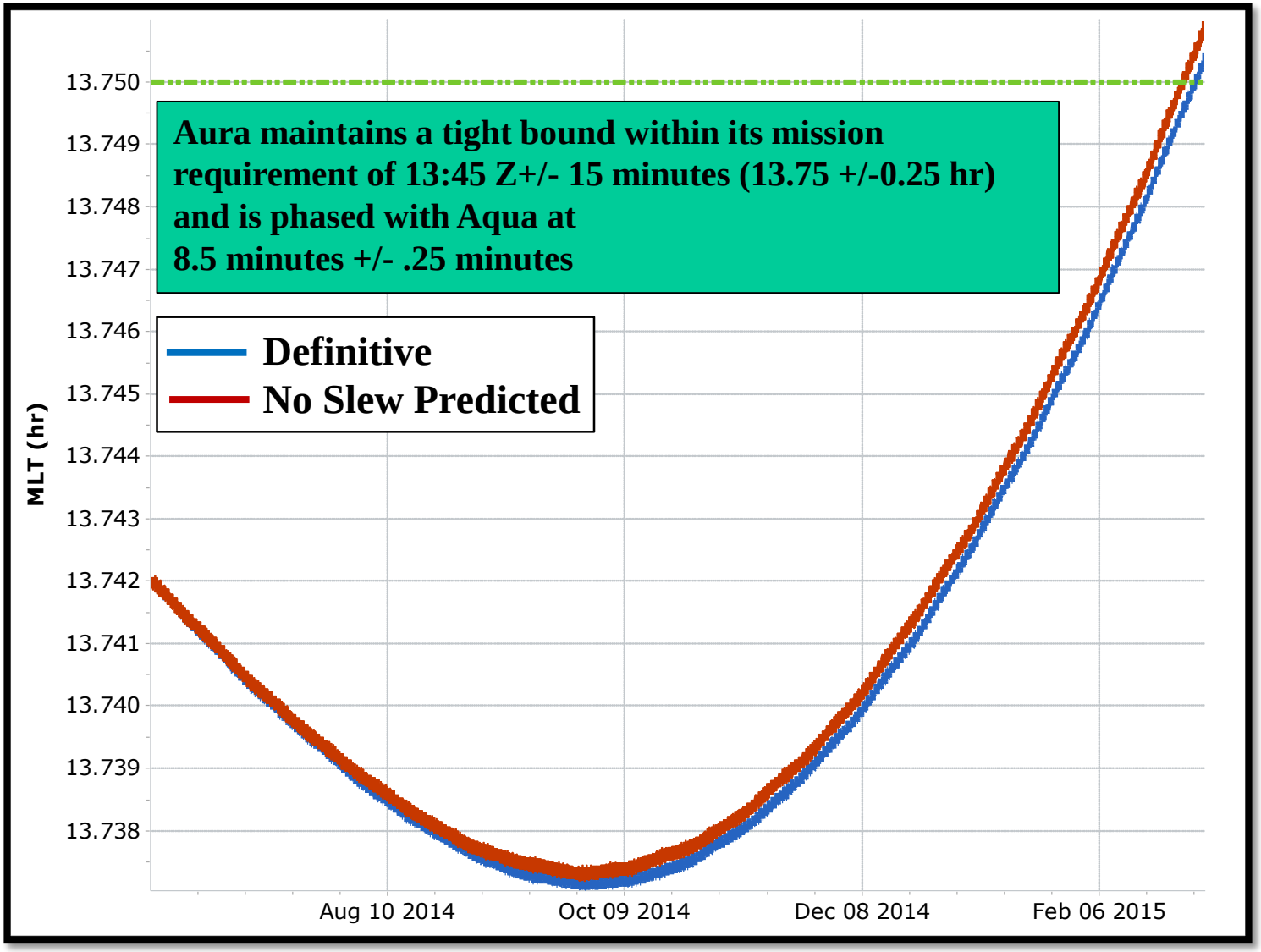
Aura Maneuver Predictions

- Between the Spring 2015 and the Spring 2016 IAM campaigns Aqua performed more maneuvers than predicted by the lifetime predictions
- Operationally, the spacecraft maneuvered more frequently due to desired WRS "buffer" not yet accounted for in Lifetime predictions

Maneuver Type	Definitive Maneuver Count	Summer 2015 Lifetime Count
RMM – No Slew	(1) *	-
DMU - Slewed Frozen Orbit	0	0
DMU – No Slew Mirror Pole	8	6
DMU – No Slew Frozen Orbit	5	1
Total	14	7

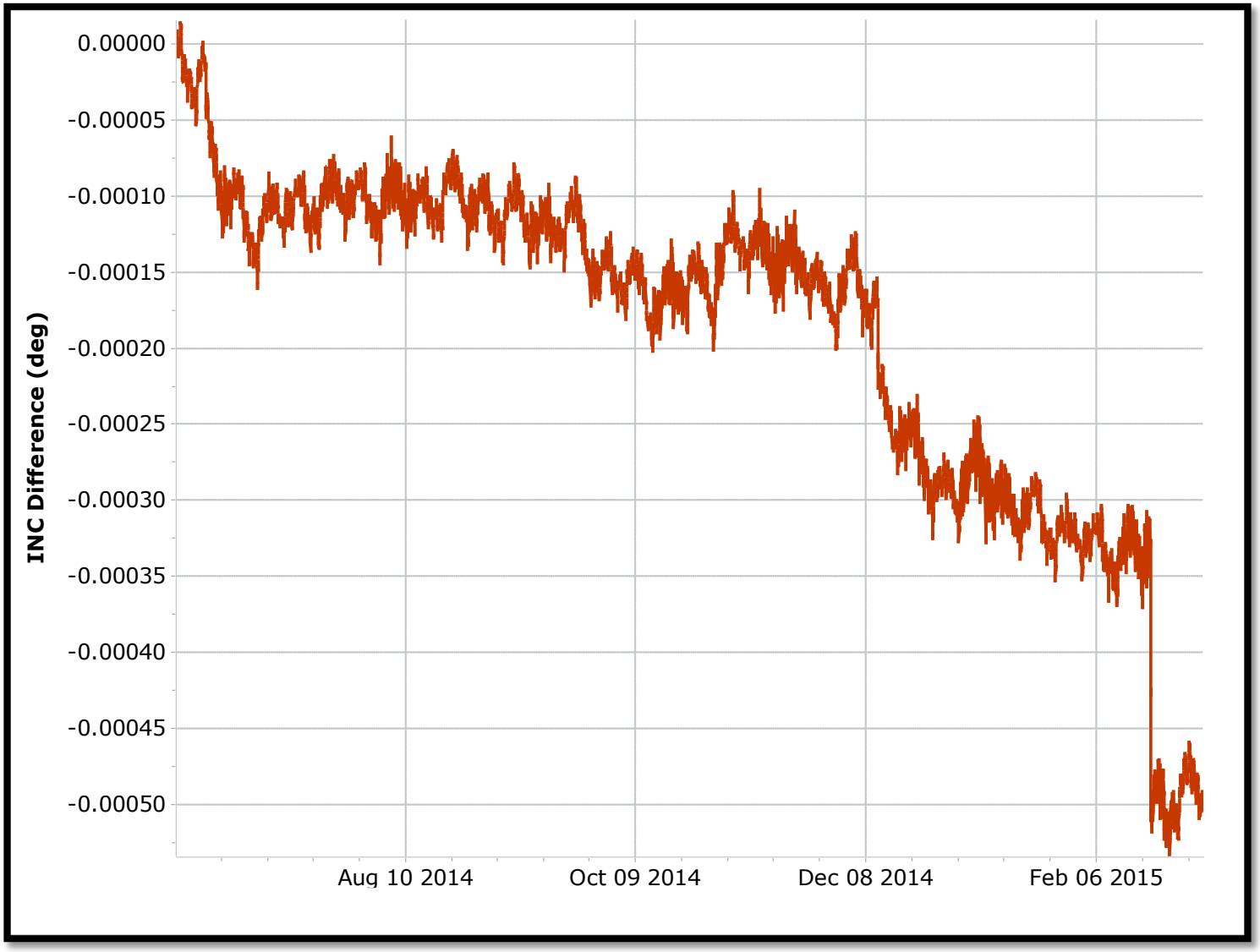
*Occurred at Mirror Pole location

Aura MLT Zoom



Aura MLT Difference: Definitive - Predicted

Aura Inclination Difference: Definitive - Predicted



Aura RAAN Difference: Definitive - Predicted

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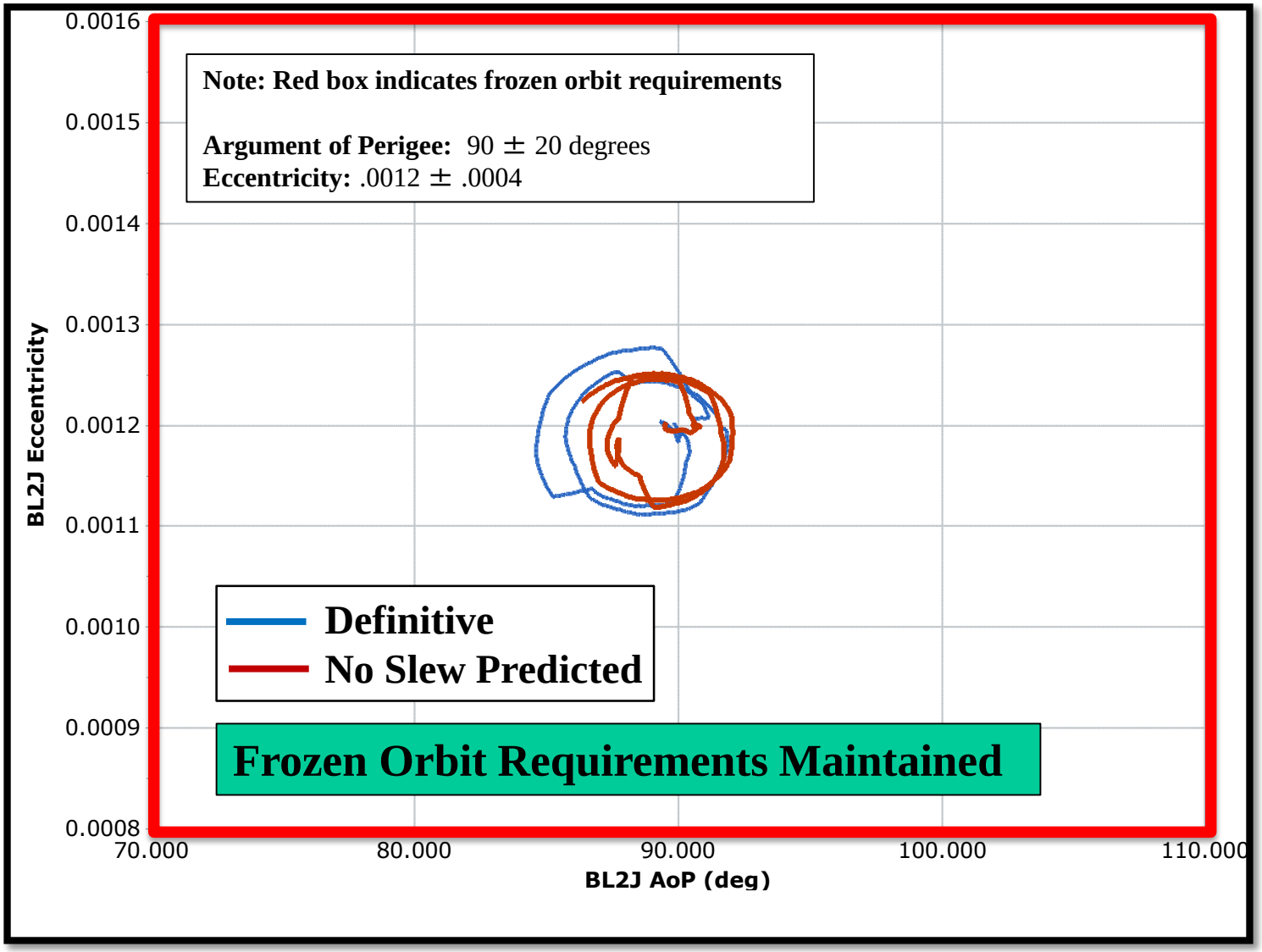
Aura Comparison of Frozen Orbit Parameters



Conclusions

- Analysis has shown that minimal (2-3) frozen orbit maneuvers per year should be sufficient to maintain long-term frozen orbit requirements
  - Frozen orbit adequately maintained in 2015
- ±2 seconds/year error goal for MLT prediction was achieved for 2015 using post-INC predictions
  - Each IAM series will "reset" Aqua and Aura's MLT
- The under prediction of the drag environment during 2015 has had some impact on MLT and frozen orbit prediction accuracy due to the substantial increase in number of maneuvers executed